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Trace Element and Radionuclide Concentrations in Walker River Bottom Sediment and Weber Reservoir Sediment Core, West-Central Nevada, 2005

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ABSTRACT

The Walker River Paiute Tribe is concerned that operations at the Yerington copper mine in Lyon County, Nevada, have contaminated water resources on the Walker River Indian Reservation. Mining in the Walker River Basin, including at the Yerington site, began in the mid-1800s; large-scale open-pit mining began in 1952 and continued intermittently until closure of the mine in 2000 because of bankruptcy. Investigations authorized by the Comprehensive Environmental Response, Compensation, and Liability Act began in the late 1990s in response to reports that elevated concentrations of trace elements and radionuclides have been measured in ground water, tailings leachate, and leachate-contaminated soil samples. The U.S. Geological Survey, in cooperation with the Walker River Paiute Tribe, began an investigation in 2005 to establish a chronology of the sediment quality of Weber Reservoir. Bottom-sediment samples were collected from six river sites and one drain site tributary to Weber Reservoir and two sediment cores were collected from Weber Reservoir for determination of selected major and trace elements, and radionuclides. Construction of Weber Reservoir began in 1933, storage began in 1934, and construction of the dam was completed in 1935.

Mean concentrations and activities of constituents measured in bottom-sediment samples from river sites, both upstream and downstream of the mine, and from the drain site downstream of mine tailings, generally were lower than those measured in the reservoir sediment. Advisory concentrations for iron and manganese were exceeded in all the samples and the advisory concentration for arsenic was equaled in one riverbed sample collected downstream of the mine. The concentration of mercury in one reservoir sample collected from pre-reservoir sediment was near the advisory concentration, and all samples, except one river-bottom sample, exceeded a sediment effects threshold concentration that may adversely affect freshwater invertebrates. No other advisory concentration or activity in the sediment samples was exceeded.

Cesium-137 data from a sediment core collected from Weber Reservoir show a clearly defined peak in sediment from a depth of 2.2–2.5 feet below the sediment surface and initial detection was in the sample from a depth of 2.8–3.2 feet. Assuming a linear rate of sedimentation and neglecting density compaction, sediment accumulated in Weber Reservoir at a rate of 0.06 feet per year during the 70 years since construction of the reservoir was completed. Each 0.3-foot length of sediment core represents about 5.5 years.

Maximum concentrations of aluminum, arsenic, beryllium, cadmium, copper, iron, lead, manganese, thorium, and zinc measured in the core were from the subsample that represents sedimentation during 1957–62. Of the 37 other analytes measured, 17 also had maximum

concentrations in this subsample. Maximum concentrations of chromium and nickel were from the subsample deposited during 1979–84 and maximum concentrations of uranium were from two adjacent subsamples deposited before the reservoir was constructed until 1944. Radium-226, radium-228, and gross alpha radioactivity had maximum activities in the subsamples from the interval deposited during 1968–73 and gross beta radioactivity had maximum activities in two adjacent subsamples deposited during 1940–51. Maximum concentrations of mercury and molybdenum were from the subsample deposited during 1935–40.

Contaminants from the Yerington copper mine site can be delivered to Weber Reservoir by direct fallout of windborne dust, fluvial transport of dust blown from the site to drainages, stormwater runoff from the site into the river, and contaminated ground water that discharges into Wabuska Drain. Concentrations and activities of constituents of concern in the sediment-core subsamples indicate varying rates of deposition; but, because each subsample represents sediment that accumulated over 5–6 years, episodic stormwater releases from the mine site would be diluted by normal sedimentation. The samples of river-bottom sediment generally had lower concentrations and activities than the reservoir-core samples, but the differences were small because both were derived from sources with a common geology owing to more than a century of mining in the Walker River Basin.

INTRODUCTION

The Walker River Paiute Tribe is concerned that discharges from the Yerington copper mine site, located in the Singatse Range, near Yerington in Lyon County, Nevada (Fig. 1) have contaminated water resources on the Walker River Indian Reservation (WRIR). Mining at the site began in 1952, and operations stopped in 1978 because of low copper prices and depletion of copper oxide reserves. In 1985, an Administrative Order was issued by the Nevada Division of Environmental Protection that alleged illegal discharge of pollutants from former mine tailings ponds (Nevada Division of Environmental Protection, 2002, accessed March 6, 2006). The mine was sold in 1989, and a solvent extraction and electrowinning plant was constructed to recover cathode copper from low-grade stockpiles and tailings with anticipation of expanding mining operations to include the nearby MacArthur copper deposits. In the late 1990s, the U.S. Environmental Protection Agency began preliminary investigations at the Yerington Mine following allegations of unlawfully discharged pollutants into waters of Nevada and pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In November 1998, the State of Nevada ordered operations at the Yerington Mine to cease because of bankruptcy and subsequent invalidation of the corporate guaranteed environmental bond (Nevada Division of Environmental Protection, 2003, accessed March 6, 2006). However, copper leaching operations continued until January 2000. Concentrations of trace elements (aluminum, arsenic, beryllium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, thorium, uranium, and zinc), sulfate, and radionuclides have been reported in dust, sediment, and ground-water samples at levels that are greater concentrations than background (Seitz and others, 1982; James Sickles, U.S. Environmental Protection Agency Remedial Project Manager, written comm., May 2006). In 2005, the U.S. Geological Survey (USGS) began a paleolimnologic investigation at Weber Reservoir to establish a chronology of the sediment quality of the reservoir.

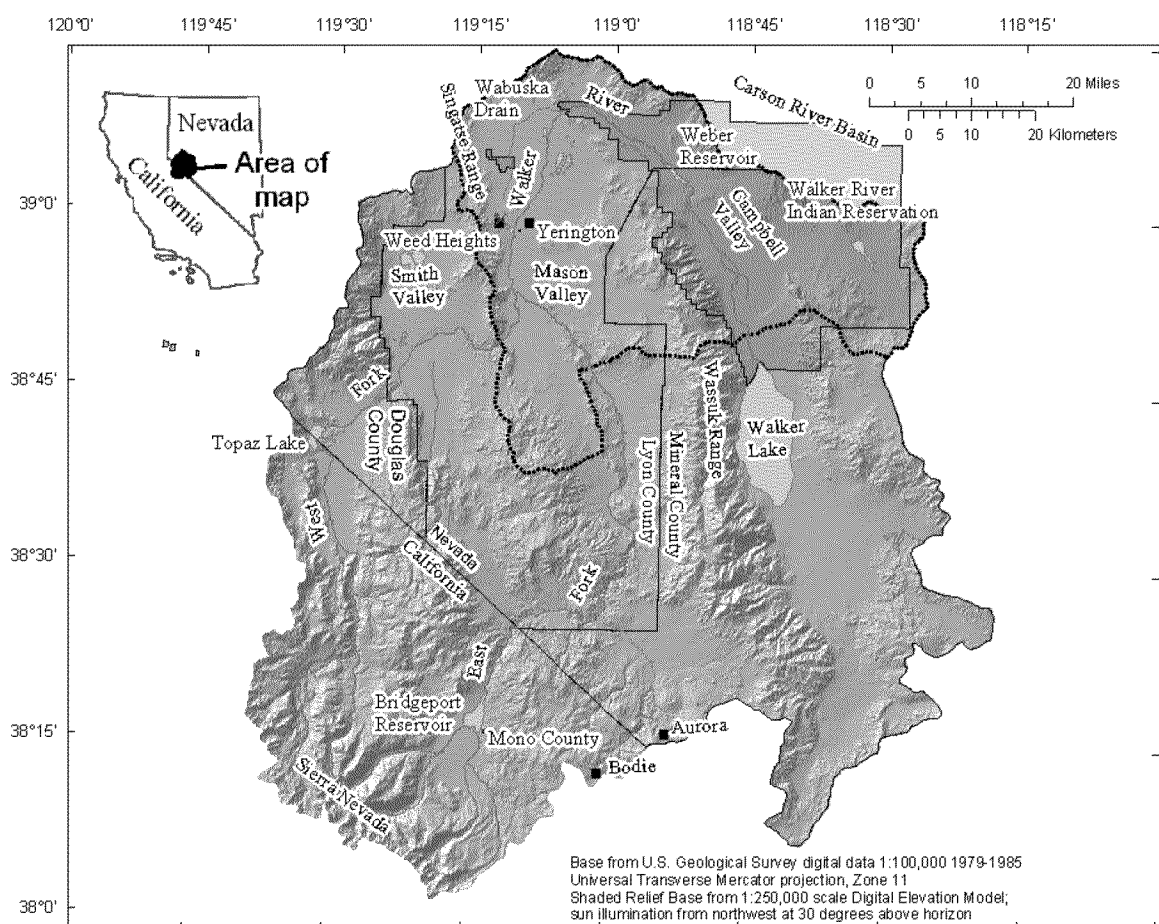


Figure 1. Location and selected geographic features of the Walker River Basin, Nevada and California, generalized extent of study area (outlined in black) and location of Yerington copper mine site (x).

Purpose and Scope

The purpose of this report is to describe concentrations of trace elements in bottom sediment from Wabuska Drain, Weber Reservoir, and the Walker River upstream of and downstream from the defunct copper mine, and to evaluate if changes occur in concentrations of trace elements in the sediment profile of Weber Reservoir that coincide in time with the operation of the copper mine. The scope of this report emphasizes data collected from six river sites, one drain site, and Weber Reservoir by the USGS in 2005. Previously published data from other investigations were used for comparison.

DESCRIPTION OF STUDY AREA

Physical Setting

Walker River Basin is a 4,050-mi² (square mile) closed hydrologic basin with headwaters in the eastern Sierra Nevada, in Mono County, California, and includes parts of Lyon, Mineral, and Douglas Counties in western Nevada. The Walker River Basin is in a transitional zone between the Sierra Nevada section of the Pacific Mountain System physiographic region and the Great Basin section of the Intermontane Plateaus physiographic region, with several mountain ranges 2,000–7,000 ft above adjacent valley floors.

The study area for this investigation is in Mason Valley and Campbell Valley in the northern part of the Walker River Basin (Fig. 2). This part of the basin is an arid, high desert with cold winters and warm summers. Average annual precipitation was 5.31 in. at the National Weather Service station at Yerington during 1971-2000 (Western Regional Climate Center, accessed March 27, 2006). Yerington is the largest community in this area with 2,883 inhabitants reported in the 2000 Census (Nevada State Library and Archives, 2000, accessed April 18, 2006). The population of WRIR was 853 in 2000, with most (721) residing in Schurz. The town of Yerington is a ranching and farming center, as well as a mining town (University of Nevada, Reno, accessed March 17, 2006). WRIR covers about 500 mi² in the northeastern part of the basin and extends into the southwestern part of the Carson River Basin (Fig. 1).

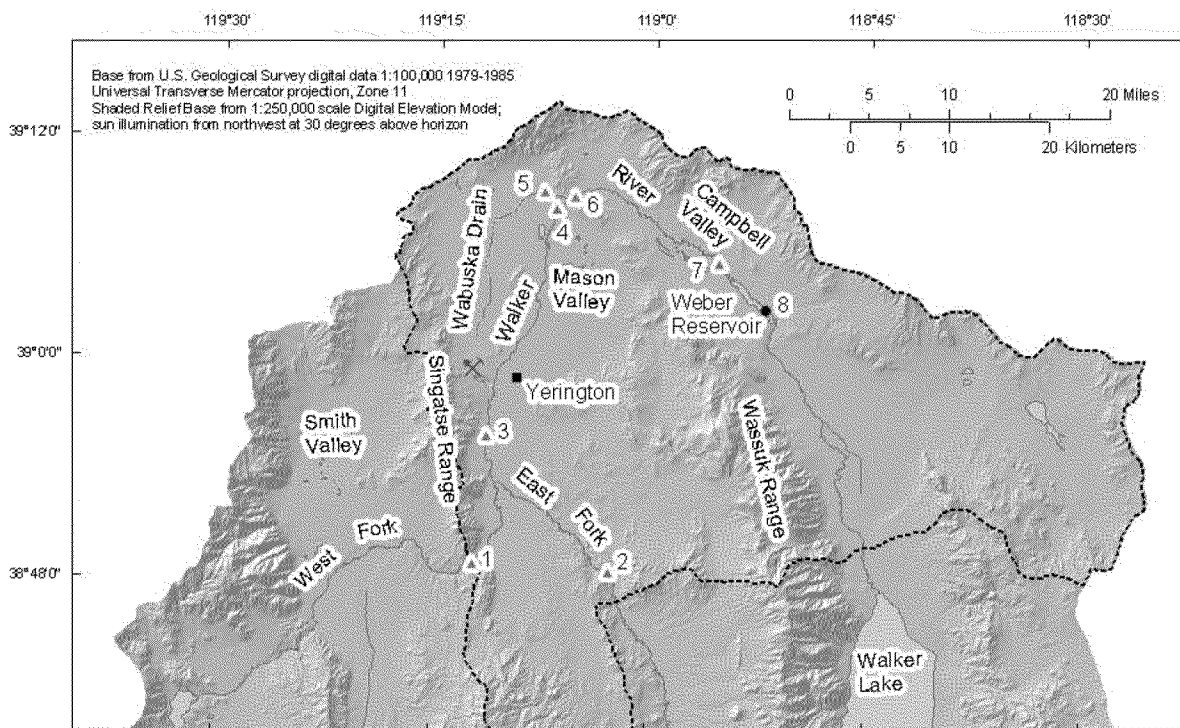


Figure 2. Location of sample-collection sites, site number (table 1; bottom-sediment site: ▲2; Weber Reservoir core site: ●8), and of Yerington copper mine site (×), northern Walker River Basin, west-central Nevada.

Geologic Setting

Consolidated rocks in the Walker River basin range in age from Triassic to Quaternary and primarily consist of quartz monzonite, granodiorite, basalt, rhyolite, and andesite. The Singatse and Wassuk Ranges are Cenozoic fault-block structures, indicating continuity with the Sierra Nevada (Moore and Archbold, 1969, p. 3). Basin-fill deposits are unconsolidated Tertiary and Quaternary alluvial sediments that underlie the valley floors and alluvial fans near the base of mountain ranges. Valley-floor sediments are fine sand, silt, and clay alluvium and playa clay and sand, and fan sediments are primarily gravel, coarse sand, and silt with some talus material (Huxel, 1969, p. 6 and 7; plate 1). Lacustrine clay deposits at least 200-ft thick are exposed near Weber Reservoir and may extend from Walker Lake to the high-water stage of Pleistocene Lake Lahontan in Mason Valley as far south as Yerington (Moore and Archbold, 1969, p. 15; Reheis, 1999). The distribution of these geologic units is generalized in figure 3 (modified from Ludington and others, 2005) to show basin fill and upland alluvium, volcanic rocks, sandstone, granitic rocks and metamorphic rocks.

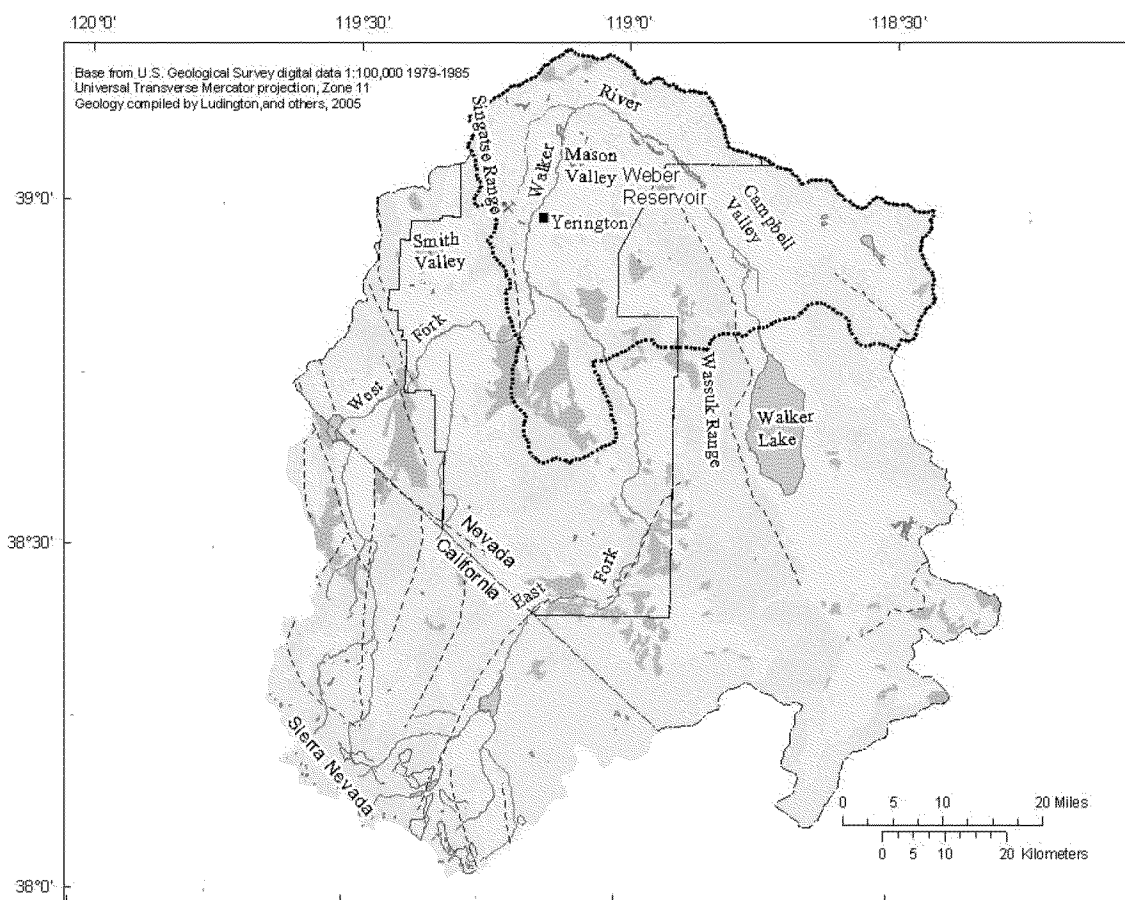


Figure 3. Generalized geologic units (basin fill and upland alluvium of Tertiary and Quaternary age, yellow; volcanic rocks of Triassic through Quaternary age, pink; sandstone of Tertiary age, orange; granitic rocks of Jurassic and Cretaceous age, green; metamorphic rocks of Ordovician through Triassic age, grey), faults (dashed black), and location of Yerington copper mine site (x), Walker River Basin, Nevada and California. (Modified from Ludington and others, 2005)

Mining Activities in the Walker River Basin

Prospecting and mining in the Walker River Basin began in the mid-1800s by individuals seeking gold and silver deposits similar to those found at the Mother Lode in California that triggered the gold rush in 1849, and later to those found at the Comstock Lode in Virginia City, Nevada (Moore and Archbold, 1969, p. 22). After 1859, numerous mining districts formed in areas surrounding the Comstock Lode, including in the Walker River Basin. Major mining districts active in the Walker River Basin during the late 1800s include Aurora (gold), Bodie (gold), and Yerington (copper), and at least nine smaller districts that mined mineral commodities including barite, coal, gypsum, iron, lead, molybdenum, nickel, silver, tin, turquoise, tungsten, uranium, and zinc (Tingley, 1992).

The Yerington mining district includes most of the Singatse Range, the northwestern Wassuk Range, and buttes protruding above Mason Valley just east of Yerington (Fig. 1; Moore and Archbold, 1969, p. 26). The district was formed in 1865, after oxidized copper ore was found in Triassic-age andesites, soda rhyolite-felsites, and limestone that had been metamorphosed by granodiorite and porphyritic quartz monzonite intrusions. Skarn and porphyry copper deposits in the district were first mined in the Singatse Range. However, the most important mineral commodity before 1900 was natural bluestone mined for copper sulfate used in the early amalgamation of silver ore from the Comstock Lode (Knopf, 1918, p. 11). By 1940, the district had earned more than \$17 million, chiefly in copper (Moore and Archbold, 1969, p.26).

The Anaconda Minerals Company began exploring the granitic rock of the Singatse Range around 1942 and began mining operations at the site 10 years later. Copper oxide ore was processed at its mill in the town of Weed Heights (Fig. 1), and, between 1953 and 1965, the mine produced more than 800 million pounds of copper worth more than \$255 million (Moore and Archbold, 1969, p. 28). About 360 million tons of ore and waste rock were removed from more than 350 acres, creating an open pit that by 1978 was 800 ft deep (Seitz and others, 1982, p. 2). Arimetco Inc. purchased the mine site in 1989 to mill low-grade copper ore stockpiles and tailings until 1996. Arimetco Inc. received permits from the State of Nevada in 1994 to develop other copper deposits, which outcrop northeast of Yerington and have an estimated copper oxide reserve of 97 million tons containing 21 percent copper (Price, 1995, p. 19).

Hydrologic Setting

The East and West Forks of the Walker River flow in a northeasterly direction into Mason Valley; there they converge into the main stem of the Walker River, which flows northward into Campbell Valley and then turns south to ultimately flow into Walker Lake (Fig. 1). During 1939–93, annual runoff averaged 133,000 acre-ft from the West Walker River (site 1); 105,000 acre-ft from the East Walker River (site 2); and 128,000 acre-ft from the main stem Walker River at Wabuska (site 6; Thomas, 1995). The 110,000 acre-ft difference between combined inflow to the main stem Walker River and the station at Wabuska (Fig. 2, site 6) represents streamflow that had evaporated, was transpired by riparian vegetation and agricultural crops, and had infiltrated to recharge ground water beneath the riverbed (Thomas, 1995).

The principal use of water in the Walker River Basin is for irrigation of crops and pastures. Extensive networks of mostly unlined canals, ditches, and drains have been constructed to convey water from the river to irrigate crops and to return excess water from fields back to the river. Several reservoirs, including Bridgeport and Weber Reservoirs, and Topaz Lake were constructed to store snowmelt runoff for release during the drier growing season. Wabuska Drain originates at the base of tailings from the Yerington copper mine and intermittently discharges to the Walker River (Brown and Caldwell, 2003). Weber Reservoir is the only reservoir on the main stem of the Walker River. The reservoir was constructed in 1934; it has a maximum storage capacity of 10,700 acre-ft and surface area of 900 acres (Stockton and others, 2004, p. 172).

The arid valley floors and semiarid mountains are the result of the rain shadow effects of the Sierra Nevada, which intercept moisture in wet storms. However, runoff in ephemeral channels in northern Mason Valley occasionally results in flash floods (Huxel, 1969, p. 21-22).

Ground water in Mason Valley is withdrawn primarily from the basin-fill deposits, which contain more than 1 million acre-ft of water in the uppermost 50 ft of saturated sediments (Huxel, 1969, p. 5). Ground water is often less than 5 ft below land surface near the river and increases with distance from the river to more than 100 ft below land surface beneath alluvial-fan deposits (Huxel, 1969, p. 13–15). Near the river, ground water can both discharge to the river and receive recharge from the river, depending on the river stage and water-table altitude.

METHODS

Selection of Sampling Sites

Bottom-sediment samples were collected from six sites along the Walker River, one site on the Wabuska Drain, and one site in Weber Reservoir. The sites and the rationale for their selection are listed in table 1, and their locations are shown in figure 2. Sites 1 through 3 were selected to characterize the chemical quality of bottom sediment in the river upstream of the Yerington mine site and sites 4 through 7 were selected to characterize the quality of sediment downstream from the mine site. Site 5 is on Wabuska Drain, an agricultural drain that intercepts shallow ground water downgradient from mine tailings, waste rock, heap leach pads, and lined and unlined process-fluid and evaporation ponds. Site 8 is in Weber Reservoir and was selected for collection of sediment cores to reconstruct the history of the chemical quality of sediment. The preferred coring location was near the dam on the thalweg of the reservoir, where sediment typically is homogeneous, fine-grained lacustrine sediment.

Table 1. Sampling sites for collection of bottom sediment and sediment cores, Walker River Basin, west-central Nevada, 2005.

[Sampling sites are assigned unique identification numbers on basis of geographic location. Eight-digit numbers are station numbers that follow "downstream order system": First two digits, or part number, refer to drainage basin, and the following six digits are downstream-order number, which is assigned according to geographic location of site in drainage basin. Stations with higher numbers are downstream from stations with lower numbers.]

Site number (fig. 2)	U.S. Geological Survey site identification	Site description	Rationale for sampling
1	10300000	West Fork Walker River near Hudson, Nev.	Background site upstream of mine
2	10293500	East Fork Walker River above Strosnider Ditch, near Mason, Nev.	Background site upstream of mine
3	10300600	Walker River near Mason, Nev.	Background site upstream of mine
4	10301497	Walker River above confluence of Perk and Joggle Slough, Nev.	Site is downstream from the mine and upstream of Wabuska Drain
5	10301495	Wabuska Drain upstream from Walker River, Nev.	Site is on drain carrying water from mine area to the Walker River
6	10301500	Walker River near Wabuska, Nev.	Site is downstream from mine and Wabuska Drain
7	10301600	Walker River above Weber Reservoir near Schurz, Nev.	Site is upstream of Weber Reservoir on tribal land
8	10301700	Weber Reservoir near Schurz, Nev. (near dam)	Cores collected to document accumulation of sediment and trace elements since reservoir storage in 1934

Collection of Bottom-Sediment Samples

Bottom-sediment samples were collected from sites 1 through 7 (Fig. 2; table 1) following protocols described by Shelton and Capel (1994). Representative samples were obtained by compositing samples from the upper 0.5 to 1 in. of sediment from 5 to 10 depositional areas at each site. Samples were collected using a Teflon spatula to transfer the sediment into a glass bowl. Composite samples were sieved through a pre-cleaned 62.5- μm (micron) nylon mesh and the resulting fine-grained fraction placed in an acid-cleaned jar.

Collection of Reservoir-Sediment Core

Two sediment cores were collected from Weber Reservoir using a boat equipped with a gravity coring system. The coring system has a polycarbonate barrel designed to avoid contamination by metals. The first core was collected on January 13, 2005, when the reservoir had an ice layer that restricted access to the preferred sampling location. This core was collected less than 500 ft from the southeastern shore of the reservoir and 2,000 ft from the dam. A 2.1-ft length of core was retrieved, packed in dry ice, and returned to the USGS laboratory in Carson City, Nev., where 38 subsamples (0.6–0.8 in. long) were extruded into individual sample jars for laboratory analysis.

The second core was collected on June 23, 2005, using the coring system described previously and a boat equipped with a depth sounder and a Global Positioning System. In addition, two sediment samples were collected from an adjacent location using a Russian peat borer-type sampler attached to rigid aluminum rods hand driven to a sediment depth that was deeper than the depth penetrated by the gravity coring apparatus. The second core was collected near Weber Dam, at the deepest point of a transect parallel to the dam. A 4.0-ft length of core was retrieved using the gravity coring device and two additional samples were collected using a Russian peat borer-type sampler from an adjacent location from depths 4.2 to 4.6 ft beneath the sediment surface. The core was taken to shore where it was suspended vertically using a tripod, and 13 subsamples (3–4 in. long) were extruded into polyethylene sample bags. The sediment collected with the Russian peat borer was divided into two 10-in. long samples and placed in separate polyethylene bags.

Laboratory Analyses

Sediment samples from the Walker River, Wabuska Drain, and Weber Reservoir were analyzed for trace elements, total and organic carbon, and selected major ions at the USGS Geologic Division laboratory in Lakewood, Colorado, using methods described by Arbogast (1996) and Taggart (2002). Radium-226 (^{226}Ra) and radium-228 (^{228}Ra) activities were determined by gamma spectrometry and gross alpha (gross α) and gross beta (gross β) radioactivities were determined by gas-flow proportional counting (Melissa Mannion, Eberline Analytical Services, written commun., 2005). Table 2 lists the constituents analyzed and their laboratory reporting levels. Cesium-137 (^{137}Cs) activity in selected sediment core subsamples collected from Weber Reservoir was measured using a high-resolution germanium well detector and a multichannel analyzer. The activity of ^{137}Cs was quantified using an energy-efficiency calibration curve from a suite of analytical-grade radioisotope standards that encompass gamma emission energies from 46 to 1,460 keV (103 electronvolts), which brackets energy emitted by ^{137}Cs (Daniel Engstrom, Science Museum of Minnesota, written commun., May 2005).

Table 2. Analytical reporting limits for constituents detected in bottom-sediment and reservoir-sediment core samples, northern Walker River Basin, west-central Nevada.

[µg/g, micrograms per gram; pct., percent; pCi/g, picocuries per gram]

Analyte	Laboratory reporting level (dry weight)	Analyte	Laboratory reporting level (dry weight)
Aluminum	8 µg/g	Molybdenum	0.50 µg/g
Antimony	0.02 µg/g	Nickel	2 µg/g
Arsenic	0.1 µg/g	Niobium	4 µg/g
Barium	0.5 µg/g	Phosphorus	0.005 pct
Beryllium	0.001 µg/g	Potassium	0.005 pct
Bismuth	0.005 µg/g	Rubidium	0.01
Cadmium	0.003 µg/g	Scandium	2 µg/g
Calcium	20 µg/g	Silver	0.1µg/g
Carbon, total	0.01 pct.	Sodium	0.005 pct
Carbon, inorganic	0.01 pct.	Strontium	2 µg/g
Carbon, organic	0.01 pct.	Sulfur	0.05 pct
Cerium	1 µg/g	Tantalum	1 µg/g
Cesium	0.003 µg/g	Thallium	1 µg/g
Chromium	1 µg/g	Thorium	1 µg/g
Cobalt	1 µg/g	Titanium	0.005 pct
Copper	1 µg/g	Uranium	0.1 µg/g
Gallium	1 µg/g	Vanadium	2 µg/g
Iron	0.005 pct	Yttrium	1 µg/g
Lanthanum	1 µg/g	Zinc	2 µg/g
Lead	1 µg/g	Radium-226	0.8 pCi/g
Lithium	1 µg/g	Radium-228	0.8 pCi/g
Magnesium	0.005 pct	Gross alpha activity	6 pCi/g
Manganese	4 µg/g	Gross beta activity	3 pCi/g
Mercury	0.02 µg/g		

CONSTITUENTS OF CONCERN

Constituents of concern are identified by the U.S. Environmental Protection Agency to be hazardous substance(s) as defined by section 101(14) of CERCLA. Constituents of concern for the Yerington copper mine site (table 3) were measured in samples from the Yerington copper mine site at levels that are greater than concentrations measured in samples collected from locations unaffected by mining operations (James Sickles, U.S. Environmental Protection Agency Remedial Project Manager, written comm., May 2006) or were identified as being potentially toxic or carcinogenic. Gross alpha and gross beta radioactivities, which are measures of radiation emitted as alpha and beta particles, respectively, also are of concern. Published advisory concentrations and activities, that is concentrations and activities of constituents in bottom sediment that have been determined to be potentially toxic to aquatic life (Ingersoll and others, 2000; Persaud and others, 1993; S.D. Luftig and S.D. Page, U.S. Environmental Protection Agency, Directive no. 9200.4-35P, written commun., April 11, 2000) also are listed in table 3. Concentrations at or exceeding advisory levels were not detected for aluminum, beryllium, boron, molybdenum, sulfate, thorium, uranium, or gross alpha and gross beta radioactivity.

CHARACTERISTICS OF RIVER AND RESERVOIR SEDIMENT SAMPLES

Results of analyses of bottom-sediment and reservoir-sediment core samples are listed in tables 4 (concentrations) and 5 (radioactivities) and summarized statistically in table 6. The bottom-sediment data represent the chemical quality of sediment that was moving within the river system in 2005. Sediment core data represent a chronologic history of sediment quality deposited in Weber Reservoir. Cores of lake sediment have been used to determine historical deposition of contaminants in locations throughout the United States (for example, Van Metre and others, 2004), including Walker Lake, Nevada (Seiler and others, 2004).

Table 3. Advisory concentrations and activities for constituents of concern detected in sediment at Yerington copper mine, in the northern Walker Basin, west-central Nevada.

[Constituents were defined as hazardous substances on the basis of section 101(14) of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 United States Code § 9601(14). µg/g, micrograms per gram; —, no advisory available for constituent in sediment; pCi/g, picocuries per gram]

Constituent of concern	Advisory concentration or activity (dry weight, in µg/g, except as indicated)
Aluminum	—
Arsenic	¹ 33
Beryllium	—
Boron	—
Cadmium	¹ 4.98
Chromium	¹ 111
Copper	¹ 149
Iron	² 21,200
Lead	¹ 128
Manganese	² 460
Mercury	¹ 1.06
Molybdenum	—
Nickel	¹ 48.6
Radium-226	³ 5 pCi/g
Radium-228	³ 5 pCi/g
Sulfate	—
Thorium	—
Uranium	—
Zinc	¹ 459
Gross alpha radioactivity	—
Gross beta radioactivity	—

¹ Ingersoll and others, 2000.

² Persaud, and others, 1993.

³ S.D. Luftig and S.D. Page, U.S. Environmental Protection Agency, Directive no. 9200.4-35P, written commun., April 11, 2000. Advisory activity is additive (radium-226+radium-228) and is increased to 15 pCi/g for subsurface soil samples.

Table 4. Concentrations of constituents in bottom-sediment samples from Walker River, Wabuska Drain, and Weber Reservoir, northern Walker River Basin, Nevada, 2005

[ft, feet; μm , micron; <, actual value is less than value shown]

Site no. (fig. 2)	Sample date	Depth, (ft below sediment surface)	Estimated period of sedimentation	Fraction	Concentration, dry weight, in micrograms per gram, except as indicated							
					Aluminum	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cadmium	Calcium
1	04/26/2005	0–.07	2004-2005	<63 μm	79,000	1.6	19	1,000	2.0	0.33	0.22	23,000
2	04/28/2005	0–.07	2004-2005	<63 μm	85,000	1.9	17	1,000	2.2	0.45	0.16	24,000
3	04/26/2005	0–.07	2004-2005	<63 μm	79,000	1.7	22	1,000	2.1	0.42	0.22	20,000
4	04/25/2005	0–.07	2004-2005	<63 μm	78,000	1.6	25	900	2.1	0.44	0.23	18,000
5	04/22/2005	0–.07	2004-2005	<63 μm	78,000	1.5	19	1,000	2.2	0.36	0.19	24,000
6	04/22/2005	0–.07	2004-2005	<63 μm	81,000	1.6	24	1,000	2.3	0.45	0.24	19,000
7	04/21/2005	0–.07	2004-2005	<63 μm	82,000	1.6	33	1,000	2.3	0.42	0.17	20,000
8	06/23/2005	0–.26	2001-2005	total	87,000	2.0	18	920	3.2	0.64	0.25	19,000
8	06/23/2005	.26–.59	1996-2001	total	95,000	2.2	28	1,000	3.3	0.58	0.22	41,000
8	06/23/2005	.59–.92	1990-1996	total	96,000	2.3	22	990	3.3	0.68	0.22	19,000
8	06/23/2005	.92–1.2	1984-1990	total	94,000	2.4	26	900	3.4	0.72	0.24	22,000
8	06/23/2005	1.2–1.6	1979-1984	total	86,000	1.9	23	800	2.8	0.57	0.20	22,000
8	06/23/2005	1.6–1.9	1973-1979	total	87,000	2.0	22	820	2.9	0.59	0.20	22,000
8	06/23/2005	1.9-2.2	1968-1973	total	96,000	2.3	25	890	3.0	0.66	0.22	24,000
8	06/23/2005	2.2–2.6	1962-1968	total	91,000	2.1	26	810	3.0	0.64	0.23	25,000
8	06/23/2005	2.6–2.9	1957-1962	total	110,000	2.5	32	1,000	3.9	0.77	0.27	36,000
8	06/23/2005	2.9–3.2	1951-1957	total	91,000	2.2	24	870	3.3	0.66	0.24	23,000
8	06/23/2005	3.2–3.5	1946-1951	total	99,000	2.2	23	1,000	3.3	0.60	0.26	25,000
8	06/23/2005	3.5–3.9	1940-1946	total	89,000	2.2	24	910	3.1	0.67	0.22	28,000
8	06/23/2005	3.9–4.2	1935-1940	total	90,000	3.5	25	990	3.4	0.72	0.25	24,000
8	06/23/2005	4.7–5.0	Pre-reservoir	total	82,000	2.2	24	850	3.3	0.61	0.22	25,000

Table 4. Concentrations of constituents in bottom-sediment samples from Walker River, Wabuska Drain, and Weber Reservoir, northern Walker River Basin, Nevada, 2005--Continued

Site no. (fig. 2)	Concentration, dry weight, in micrograms per gram, except as indicated												
	Depth, (ft below sediment surface)	Carbon, total (percent)	Carbon, inorganic (percent)	Carbon, organic (percent)	Cerium	Cesium	Chromium	Cobalt	Copper	Gallium	Iron	Lanthanum	Lead
1	0-.07	1.6	0.08	1.6	74	14	49	15	49	19	42,000	34	21
2	0-.07	1.1	0.09	1.0	83	9	44	15	43	20	42,000	39	21
3	0-.07	1.8	0.06	1.8	73	11	40	15	47	19	40,000	33	21
4	0-.07	2.1	0.03	2.1	73	12	38	14	55	20	42,000	33	21
5	0-.07	0.94	0.12	0.82	83	11	45	15	48	19	44,000	38	19
6	0-.07	2.0	0.05	2.0	73	12	40	14	53	20	42,000	34	21
7	0-.07	1.4	0.04	1.3	81	11	43	15	51	20	44,000	38	20
8	0-.26	1.3	0.05	1.2	86	16	39	19	66	24	54,000	44	27
8	.26-.59	1.4	0.52	0.90	86	15	41	20	61	25	52,000	43	28
8	.59-.92	0.90	0.04	0.86	94	18	44	20	71	25	58,000	48	28
8	.92-1.2	1.2	0.13	1.1	93	18	44	20	74	26	59,000	47	28
8	1.2-1.6	1.2	0.2	1.0	80	16	68	17	66	22	53,000	40	24
8	1.6-1.9	1.2	0.2	1.0	83	16	40	17	67	23	53,000	42	25
8	1.9-2.2	1.2	0.22	1.0	88	17	44	19	73	25	58,000	44	27
8	2.2-2.6	1.3	0.28	1.0	83	17	42	18	70	24	56,000	42	26
8	2.6-2.9	1.4	0.34	1.0	107	20	52	23	84	30	70,000	54	31
8	2.9-3.2	1.2	0.18	1.0	91	18	44	19	71	25	58,000	46	27
8	3.2-3.5	0.98	0.18	0.80	92	17	42	20	69	25	57,000	46	26
8	3.5-3.9	1.2	0.32	0.86	89	17	42	18	66	23	55,000	45	25
8	3.9-4.2	1.2	0.13	1.1	93	17	43	19	62	24	52,000	47	27
8	4.7-5.0	1.3	0.28	0.98	83	15	38	17	61	22	50,000	42	24

Table 4. Concentrations of constituents in bottom-sediment samples from Walker River, Wabuska Drain, and Weber Reservoir, northern Walker River Basin, Nevada, 2005--Continued

Site no. (fig. 2)	Concentration, dry weight, in micrograms per gram, except as indicated												
	Depth, (ft below sediment surface)	Lithium	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Niobium	Phosphorus	Potassium	Rubidium	Scandium	Silver
1	0-.07	41	13,000	1,200	0.04	1.4	23	15	1,400	1,400	80	13	<3
2	0-.07	35	12,000	870	0.50	1.7	22	19	1,300	1,300	88	13	<3
3	0-.07	39	12,000	1,500	0.32	1.6	22	15	1,300	1,300	80	12	<3
4	0-.07	42	13,000	1,400	0.31	1.9	23	15	1,300	1,300	81	13	<3
5	0-.07	50	14,000	1,000	0.04	2.3	23	16	1,400	1,400	96	13	<3
6	0-.07	42	14,000	2,000	0.26	1.6	23	15	1,400	1,400	86	13	<3
7	0-.07	41	12,000	1,700	0.29	1.8	23	17	1,400	1,400	90	13	<3
8	0-.26	67	17,000	1,370	0.34	3.4	25	17	1,200	24,000	140	17	<3
8	.26-.59	63	16,000	1,300	0.30	5.4	25	17	1,200	25,000	130	17	<3
8	.59-.92	71	19,000	1,500	0.43	2.9	27	18	1,300	25,000	140	18	<3
8	.92-1.2	74	18,000	1,500	0.43	3.5	28	18	1,300	24,000	140	19	<3
8	1.2-1.6	66	17,000	1,400	0.33	3.0	38	16	1,200	21,000	120	17	<3
8	1.6-1.9	66	17,000	1,400	0.43	3.0	25	16	1,200	22,000	120	17	<3
8	1.9-2.2	69	19,000	1,400	0.50	3.7	27	18	1,400	23,000	130	19	<3
8	2.2-2.6	63	18,000	1,500	0.32	3.4	27	17	1,300	22,000	120	18	<3
8	2.6-2.9	83	22,000	1,900	0.30	4.6	33	20	1,600	27,000	160	23	<3
8	2.9-3.2	72	19,000	1,600	0.34	4.5	28	17	1,300	23,000	140	19	<3
8	3.2-3.5	68	20,000	1,600	0.28	3.3	26	18	1,300	26,000	150	19	<3
8	3.5-3.9	71	18,000	1,500	0.42	5.3	26	17	1,300	24,000	140	18	<3
8	3.9-4.2	71	16,000	1,400	1.0	7.7	25	17	1,200	25,000	140	17	<3
8	4.7-5.0	65	16,000	1,400	0.47	4.8	24	16	1,200	22,000	130	16	<3

Table 4. Concentrations of constituents in bottom-sediment samples from Walker River, Wabuska Drain, and Weber Reservoir, northern Walker River Basin, Nevada, 2005--Continued

Site no. (fig. 2)	Concentration, dry weight, in micrograms per gram, except as indicated											
	Depth, (ft below sediment surface)	Sodium	Strontium	Sulfur (percent)	Tantalum	Thallium	Thorium	Titanium	Uranium	Vanadium	Yttrium	Zinc
1	0-.07	17,000	540	0.07	1.1	0.60	16	6,600	6.5	120	20	100
2	0-.07	19,000	530	0.08	1.4	0.71	18	6,700	5.6	130	22	99
3	0-.07	16,000	500	0.11	1.1	0.66	14	6,000	5.6	110	18	95
4	0-.07	13,000	430	0.13	1	0.66	15	5,800	6.5	110	18	100
5	0-.07	18,000	560	0.08	1.1	0.70	17	6,700	6.1	120	21	110
6	0-.07	14,000	460	0.11	0.95	0.66	15	5,900	5.8	120	19	100
7	0-.07	16,000	500	0.08	1.2	0.70	17	6,600	6.2	130	21	100
8	0-.26	12,000	440	0.14	1.2	0.91	20	5,100	10	140	26	130
8	.26-.59	17,000	620	0.19	1.1	0.91	20	5,000	10	140	26	120
8	.59-.92	13,000	450	0.19	1.2	0.97	22	5,600	9.0	150	27	140
8	.92-1.2	12,000	450	0.26	1.3	0.96	22	5,400	10	150	27	140
8	1.2-1.6	10,000	400	0.25	1.1	0.82	19	4,900	8.0	140	24	130
8	1.6-1.9	11,000	410	0.20	1.1	0.84	19	4,900	9.0	140	24	130
8	1.9-2.2	11,000	430	0.23	1.3	0.91	22	5,300	9.0	150	26	140
8	2.2-2.6	10,000	410	0.24	1.3	0.86	20	5,000	9.0	140	25	130
8	2.6-2.9	13,000	550	0.28	1.4	1.0	26	6,300	11	180	32	170
8	2.9-3.2	11,000	440	0.22	1.2	0.91	22	5,400	11	150	27	140
8	3.2-3.5	14,000	480	0.19	1.2	0.94	22	5,600	9.0	150	28	140
8	3.5-3.9	12,000	460	0.21	1.2	0.90	21	5,200	12	150	26	130
8	3.9-4.2	14,000	510	0.29	1.2	0.98	22	5,100	12	140	26	130
8	4.7-5.0	12,000	450	0.23	1.1	0.87	20	4,800	11	130	26	120

Table 5. Activities of radioactive constituents in bottom-sediment samples from Walker River, Wabuska Drain, and Weber Reservoir, northern Walker River Basin, Nevada, 2005

Site no. (fig. 2)	Activity, dry weight, in picocuries per gram				
	Depth, (ft below sediment surface)	Gross alpha radioactivity	Gross beta radioactivity	Radium-226	Radium-228
1	0–.07	24	32	0.9	1.1
2	0–.07	27	33	1.5	2.0
3	0–.07	29	28	1.3	1.5
4	0–.07	21	32	1.3	1.7
5	0–.07	16	25	1.0	1.1
6	0–.07	26	30	1.0	1.3
7	0–.07	31	30	1.1	1.3
8	0–.26	24	32	1.4	2.0
8	.26–.59	26	38	1.7	2.1
8	.59–.92	21	40	1.4	2.1
8	.92–1.2	24	36	1.8	2.4
8	1.2–1.6	27	37	1.4	2.0
8	1.6–1.9	30	32	1.6	1.8
8	1.9–2.2	32	33	2.1	2.5
8	2.2–2.6	22	36	1.2	2.2
8	2.6–2.9	20	31	1.3	1.9
8	2.9–3.2	17	35	1.4	2.1
8	3.2–3.5	28	43	1.1	1.4
8	3.5–3.9	24	43	1.1	1.6
8	3.9–4.2	23	32	1.2	1.6
8	4.7–5.0	23	38	1.3	1.9

Table 6. Statistical summary of concentrations and activities of constituents in bottom sediment and Weber Reservoir sediment samples, northern Walker River Basin, Nevada, 2005

[Concentrations and activity values are rounded. pct., percent; pCi/g, picocuries per gram; <, actual value is less than value shown]

Constituent	Concentration (micrograms per gram, dry weight, except as indicated)							
	Stream-bottom sediment samples				Weber Reservoir sediment-core samples			
	<i>Maximum</i>	<i>Minimum</i>	<i>Median</i>	<i>Mean</i>	<i>Maximum</i>	<i>Minimum</i>	<i>Median</i>	<i>Mean</i>
Aluminum	85,000	78,000	79,000	80,000	110,000	82,000	91,000	92,000
Antimony	1.9	1.5	1.6	1.6	3.5	1.9	2.2	2.3
Arsenic	33	17	22	23	32	18	24	24
Barium	1,100	910	1,000	1,000	1,000	800	910	920
Beryllium	2.3	2.0	2.2	2.2	3.9	2.8	3.3	3.2
Bismuth	0.45	0.33	0.42	0.41	0.77	0.57	0.65	0.65
Cadmium	0.24	0.16	0.22	0.20	0.27	0.20	0.23	0.23
Calcium	24,000	18,000	20,000	21,000	41,000	19,000	24,000	25,000
Carbon, total (pct.)	2.1	0.94	1.6	1.6	1.4	0.90	1.2	1.2
Carbon, inorganic (pct.)	0.12	0.03	0.06	0.07	0.52	0.04	0.20	0.22
Carbon, organic (pct.)	2.1	0.94	1.6	1.6	1.2	0.8	1.0	0.99
Cerium	83	73	74	77	110	80	88	89
Cesium	14	8.6	11	11	20	14	17	17
Chromium	48	38	43	43	68	38	42	44
Cobalt	15	14	15	15	22	17	19	19
Copper	55	43	48	49	84	61	68	69
Gallium	20	19	20	20	30	22	24	25
Iron	44,000	40,000	42,000	42,000	70,000	50,000	55,000	56,000
Lanthanum	39	33	34	36	54	40	44	45
Lead	21	19	21	20	31	24	27	26
Lithium	50	35	41	41	83	63	68	69
Magnesium	14,000	12,000	13,000	13,000	22,000	16,000	18,000	18,000
Manganese	2,000	860	1,400	1,400	1,900	1,300	1,400	1,500
Mercury	0.50	0.04	0.29	0.25	1.0	0.28	0.38	0.42
Molybdenum	2.3	1.4	1.7	1.8	7.7	2.8	3.6	4.2
Nickel	23	22	23	23	38	24	27	27
Niobium	23	15	15	16	20	16	17	17
Phosphorus	1,400	1,300	1,400	1,400	1,600	1,200	1,300	1,300
Potassium	22,000	17,000	18,000	19,000	27,000	21,000	24,000	24,000
Rubidium	96	80	86	86	160	120	140	140
Scandium	13	12	13	13	22	16	18	18

Table 6. Statistical summary of concentrations and activities (rounded) of constituents in bottom sediment and Weber Reservoir sediment samples, northern Walker River Basin, Nevada, 2005--
Continued

[Concentrations and activity values are rounded. pct., percent; pCi/g, picocuries per gram; <, actual value is less than value shown]

Constituent	Concentration (micrograms per gram, dry weight, except as indicated)							
	Stream-bottom sediment samples				Weber Reservoir sediment-core samples			
	<i>Maximum</i>	<i>Minimum</i>	<i>Median</i>	<i>Mean</i>	<i>Maximum</i>	<i>Minimum</i>	<i>Median</i>	<i>Mean</i>
Silver	<3	<3	<3	<3	<3	<3	<3	<3
Sodium	19,000	13,000	16,000	16,000	17,000	10,000	12,000	12,000
Strontium	560	430	500	500	620	400	450	460
Sulfur (pct.)	0.13	0.07	0.08	0.09	0.29	0.14	0.23	0.22
Tantalum	1.4	0.95 ^e	1.1	1.1	1.4	1.0	1.2	1.2
Thallium	0.71 ^e	0.60 ^e	0.66 ^e	0.67 ^e	1.0	0.82 ^e	0.91 ^e	0.92 ^e
Thorium	18	14	16	16	26	14	21	17
Titanium	6,700	5,800	6,600	6,300	6,300	4,800	5,200	5,300
Uranium	6.5	5.6	6.1	6.0	12	8.5	10	10
Vanadium	130	110	120	120	180	130	140	150
Yttrium	22	18	20	20	32	24	26	26
Zinc	110	95	100	100	170	120	130	140
Radium-226 (pCi/g)	1.5	0.93	1.1	1.2	2.1	1.1	1.4	1.4
Radium-228 (pCi/g)	2.0	1.1	1.3	1.4	2.5	1.4	2.0	2.0
Gross alpha activity (pCi/g)	31	16	26	25	32	17	24	24
Gross beta activity (pCi/g)	33	25	30	30	43	31	36	36
^e estimated								

Concentrations and activities of constituents in bottom-sediment samples collected upstream of the Yerington mine site (sites 1–3) were similar to concentrations in samples collected downstream from the mine site (sites 4–7). Average concentrations of arsenic, beryllium, copper, manganese, molybdenum, uranium, and zinc were higher in samples collected downstream from the mine site than in samples collected upstream, whereas average concentrations of aluminum, chromium, mercury, ^{226}Ra , ^{228}Ra , gross alpha and gross beta were higher in samples collected upstream of the mine (tables 4–5). But such small differences are not significant given the few samples of bottom sediment that were collected. The general similarity in the chemistry of the sediment samples is due to the distribution of minerals in source rock (Fig. 3) and the fluvial processes transporting sediment through the drainage basin.

Mean concentrations and activities of constituents in bottom-sediment samples generally were lower than those measured in reservoir-sediment subsamples, except for barium, organic and total carbon, phosphorus, sodium, and titanium. Strontium and gross alpha radioactivity averaged slightly higher in the bottom-sediment samples than in the reservoir-sediment samples, but the maximum radioactivities were slightly higher in the reservoir-bottom samples for both constituents (table 5). Advisory concentrations (table 3) for iron (21,200 $\mu\text{g/g}$ (micrograms per gram)) and manganese (460 $\mu\text{g/g}$) were exceeded in all bottom-sediment samples from both the river and the drain and from the reservoir-sediment cores (table 4). The advisory concentration for arsenic (33 $\mu\text{g/g}$) was equaled in one bottom-sediment sample collected at site 7 (Fig. 2; table 4). The concentration of mercury in one reservoir sample (1.00 $\mu\text{g/g}$) collected from pre-reservoir sediment is near the advisory concentration (1.06 $\mu\text{g/g}$; table 3). Concentrations of mercury in all samples, except two bottom-sediment samples (Fig. 2; sites 1 and 2) exceeded the concentration of mercury in sediment that may begin to adversely affect freshwater invertebrates (Ontario, Canada, sediment effects threshold concentration for freshwater invertebrates, 0.2 $\mu\text{g/g}$; Persaud and others, 1993). Elevated concentrations of mercury that have been documented in sediment, water, and biota samples from the East Fork and the main stem of the Walker River are attributed to 19th century mining of gold and silver from the Bodie and Aurora mining districts (Seiler and others, 2004, p. 14). Concentrations for the remaining constituents listed in table 3 did not equal or exceed the advisory concentration or activity.

Cesium-137 was measured in selected subsamples from the reservoir-sediment cores to determine the rate of sediment accumulation in Weber Reservoir and to estimate the timing of changes in sediment chemistry. Above-ground weapons testing first introduced ^{137}Cs to the atmosphere around 1950, and releases peaked in 1963. Thus, the earliest (deepest) detection of ^{137}Cs in a sediment profile corresponds with 1950, and the maximum ^{137}Cs activity corresponds with 1963. Identification of the pre-reservoir surface is an independent marker for 1934 because accumulation of sediment in Weber Reservoir began with its construction in 1934.

The ^{137}Cs data from the core collected from Weber Reservoir in January 2005 indicate that the core did not include the entire sediment profile and also that sediment may have been redistributed by near-shore wave action (Fig. 4). The core collected in June shows a clearly defined peak in ^{137}Cs (1963) in the subsample collected from 2.2 to 2.5 ft below the reservoir-sediment surface and an initial detection of ^{137}Cs (1950) in the subsample from 2.8 to 3.2 ft below the sediment surface (Fig. 4). One of the two sediment samples collected using the Russian peat borer-type sampler is believed to have been contaminated during retrieval. A slide hammer was used to drive the sampler into stiff pre-reservoir sediment, and the hinged cover designed to isolate the sediment sample during retrieval could not be closed completely. Assuming a linear rate of sedimentation and neglecting density compaction, sediment accumulated in Weber Reservoir at 0.07 ft/yr (foot per year) during 1934–50, 0.04 ft/yr during 1950–63, and 0.06 ft/yr during 1963–2005. An average sedimentation rate of 0.06 ft/yr was assumed for the 71-year period 1934–2005.

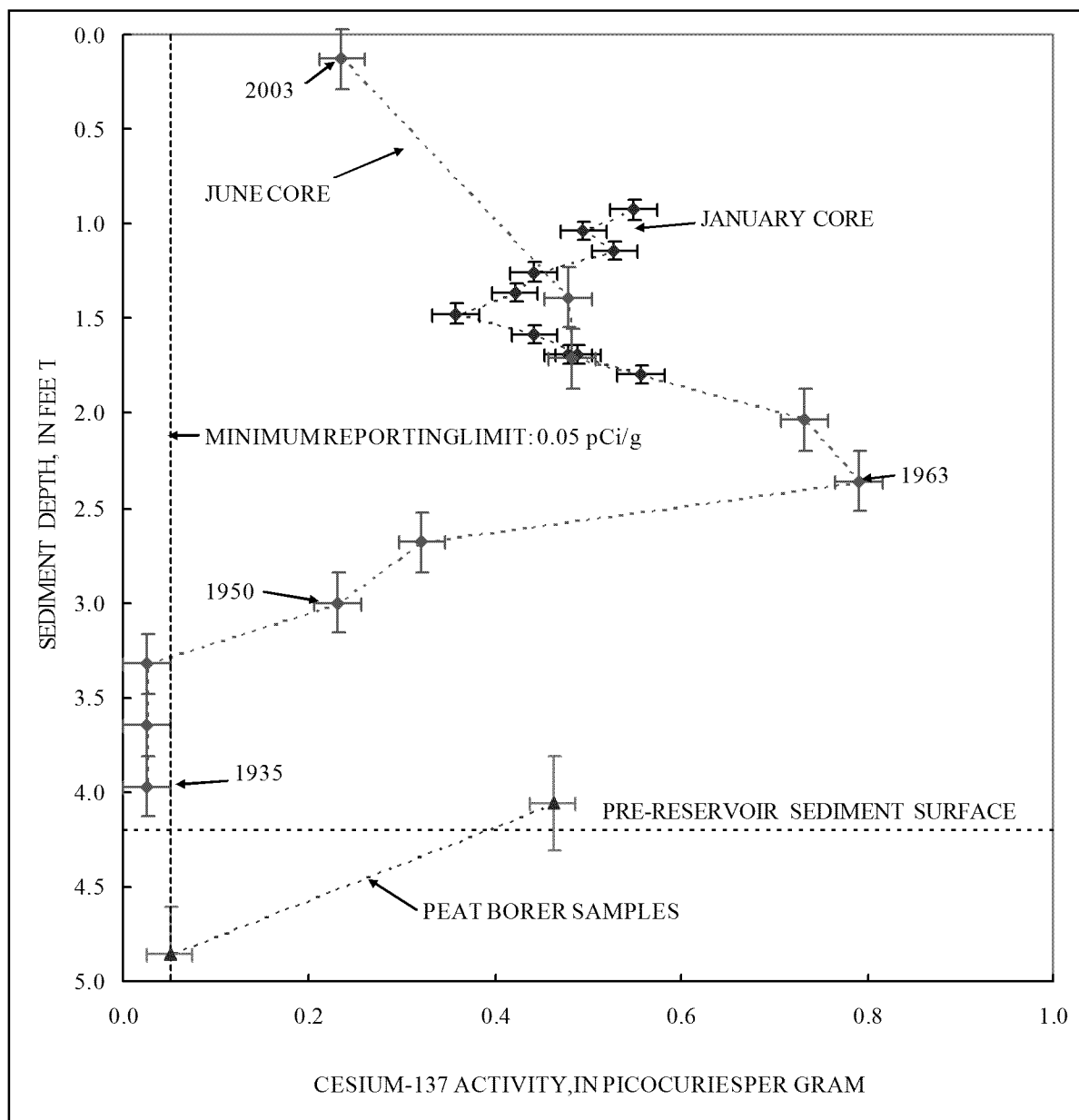


Figure 4. Distribution of cesium-137 in sediment cores collected from Weber Reservoir in the northern Walker River Basin, west-central Nevada, on January 13 and June 23, 2005.

Profiles of concentrations and activities of the 19 constituents of concern detected in the sediment core collected from Weber Reservoir are shown in figure 5. Also shown in figure 5 are estimated years of sediment deposition determined assuming a linear sedimentation rate of 0.06 ft/yr. Age estimates are plus or minus 2 to 3 years because each subsample was 0.2–0.3 ft in length. The estimated age of the subsample collected using the peat borer (4.7–5.0 ft beneath the sediment surface) is not reliable because pre-reservoir sediments were subject to the variable fluvial actions of the Walker River.

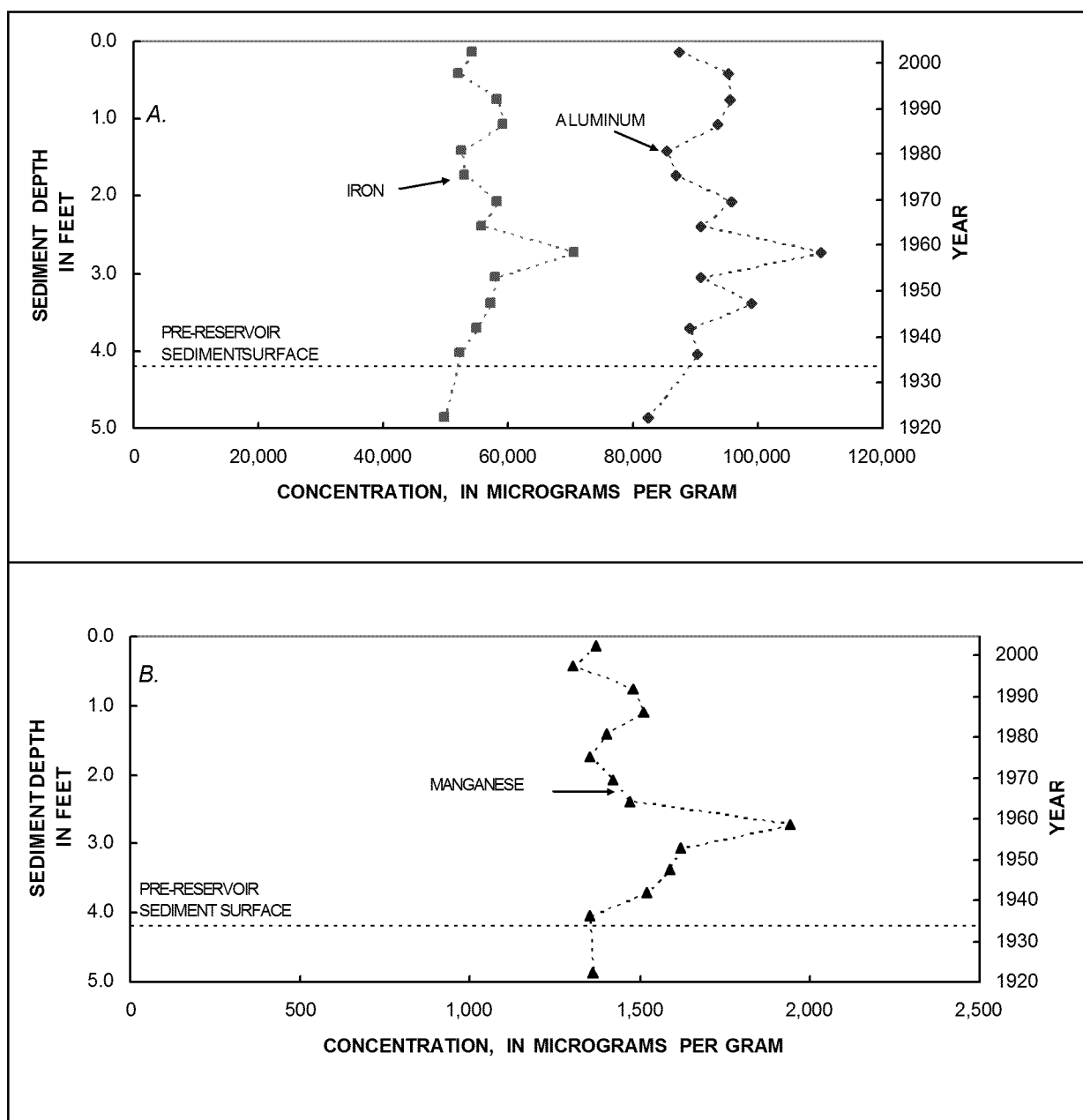


Figure 5. Concentrations or activities of constituents of concern in sediment, as a function of depth and time in Weber Reservoir, in the northern Walker River Basin, Nevada, on June 23, 2005. The year of deposition was estimated assuming a deposition rate of 0.06 foot per year and no sediment compaction. *A*, aluminum and iron. *B*, manganese. *C*, copper, lead, and zinc. *D*, arsenic, nickel, and chromium. *E*, thorium and uranium. *F*, beryllium and molybdenum. *G*, cadmium and mercury. *H*, radium-226 and radium-228. *I*, gross alpha and gross beta.

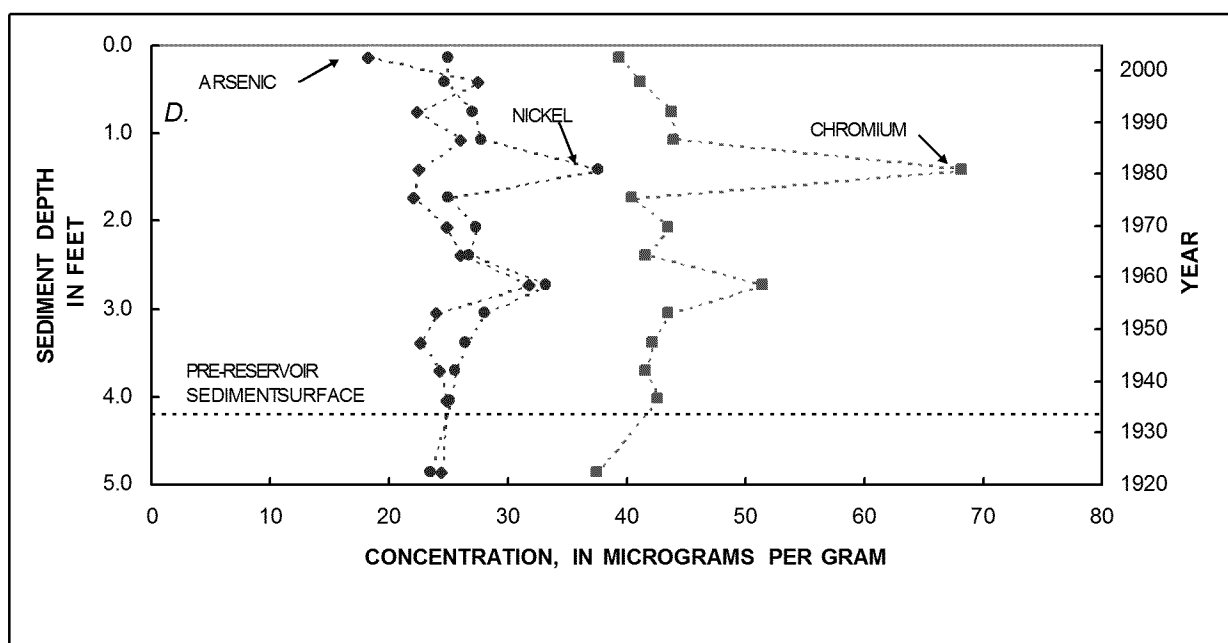
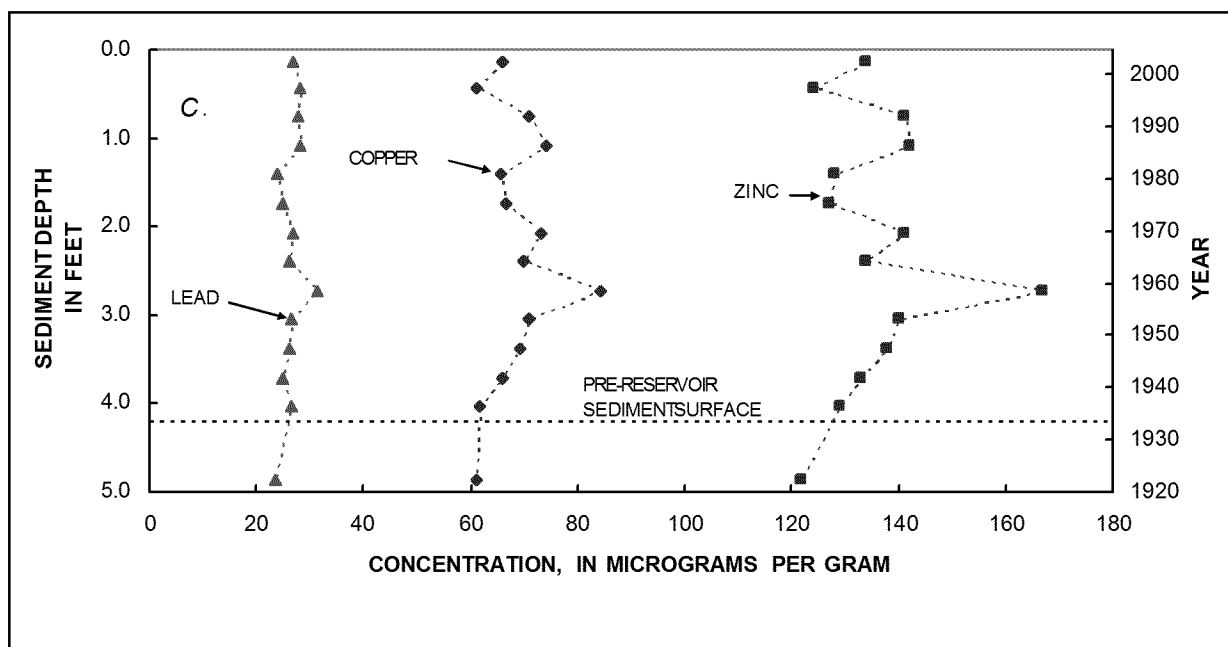


Figure 5. Concentrations or activities of constituents of concern in sediment, as a function of depth and time in Weber Reservoir, in the northern Walker River Basin, Nevada, on June 23, 2005. The year of deposition was estimated assuming a deposition rate of 0.06 foot per year and no sediment compaction—Continued.

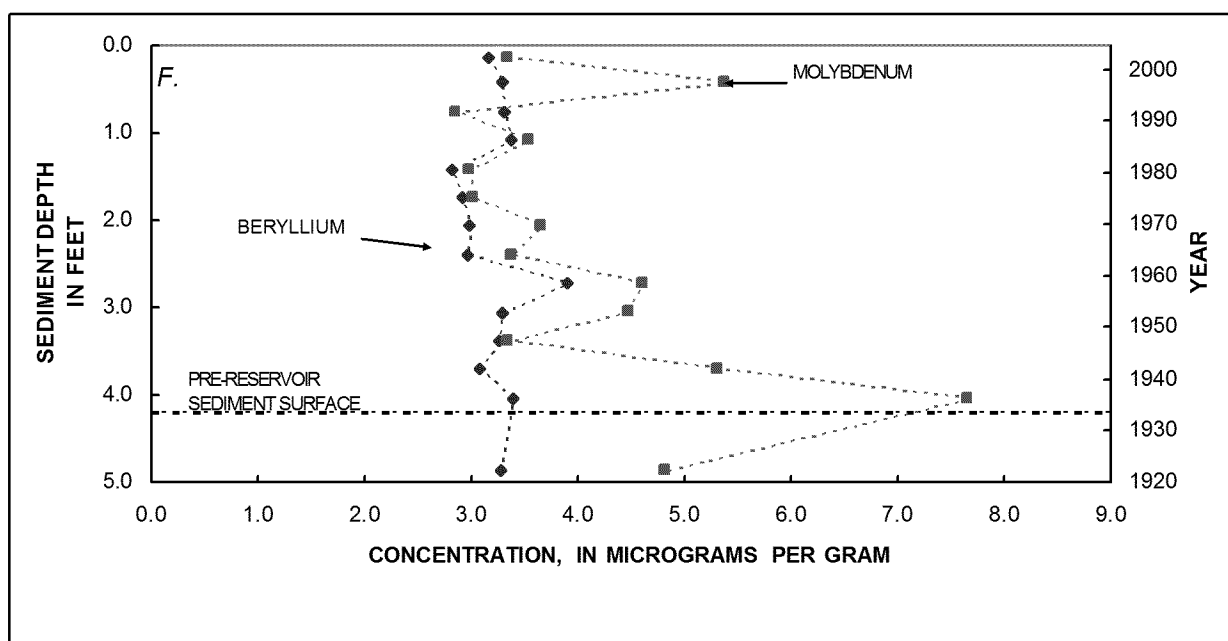
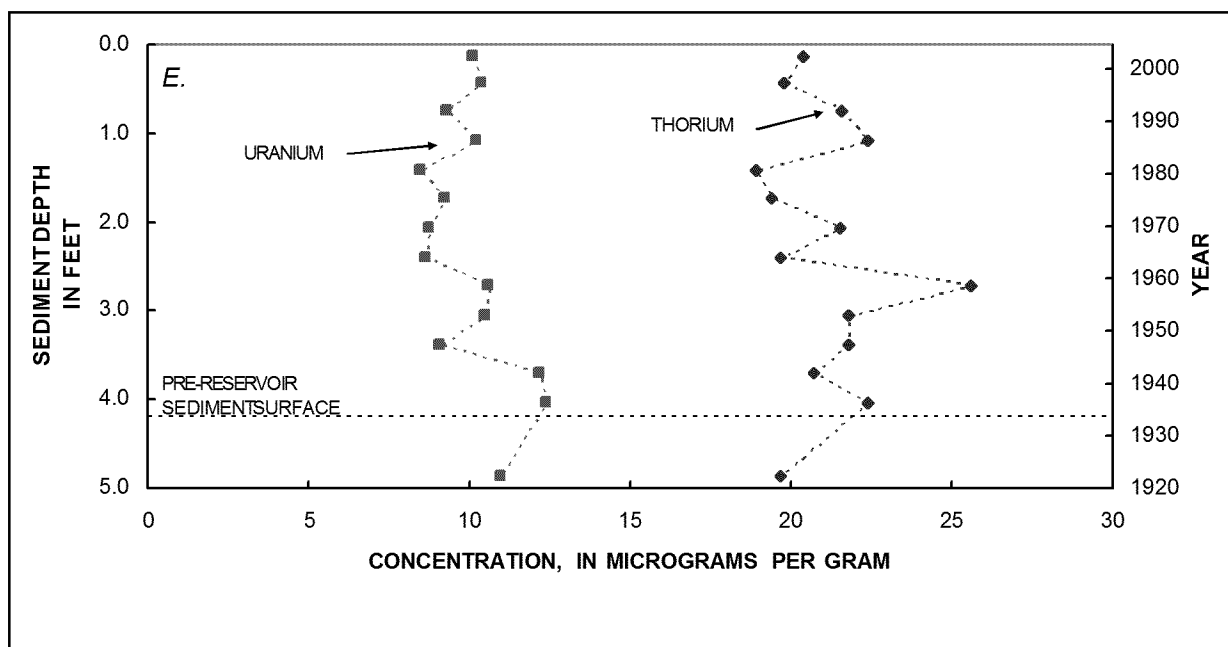


Figure 5. Concentrations or activities of constituents of concern in sediment, as a function of depth and time in Weber Reservoir, in the northern Walker River Basin, Nevada, on June 23, 2005. The year of deposition was estimated assuming a deposition rate of 0.06 foot per year and no sediment compaction--Continued.

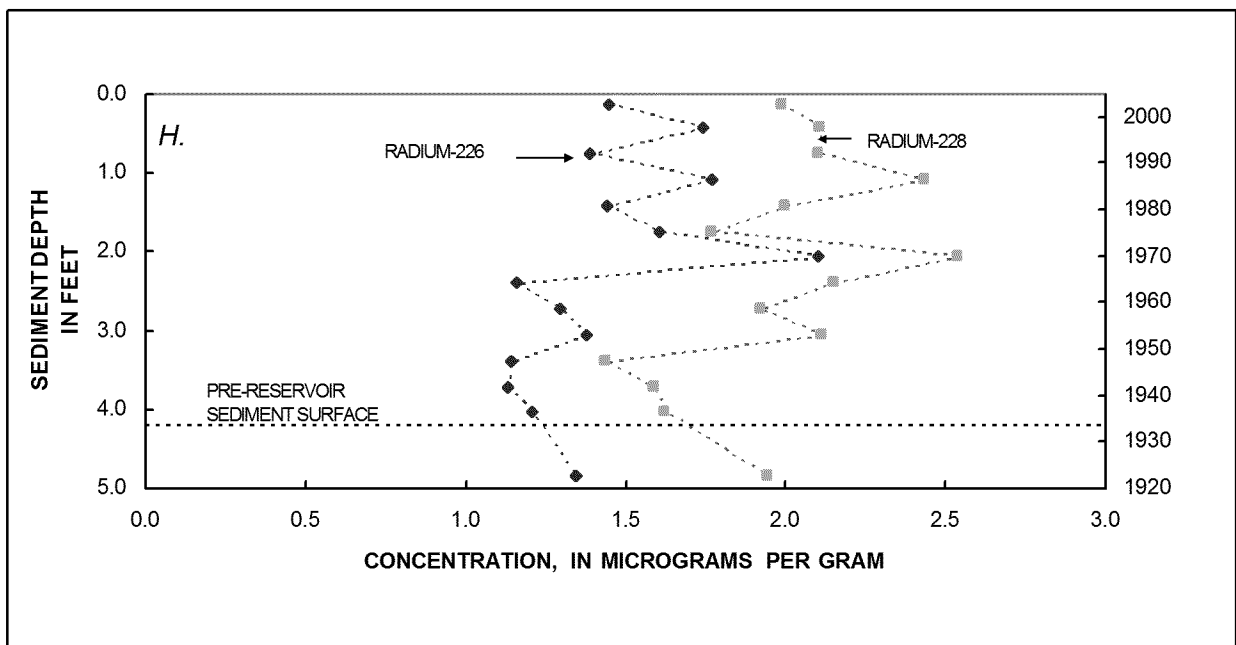
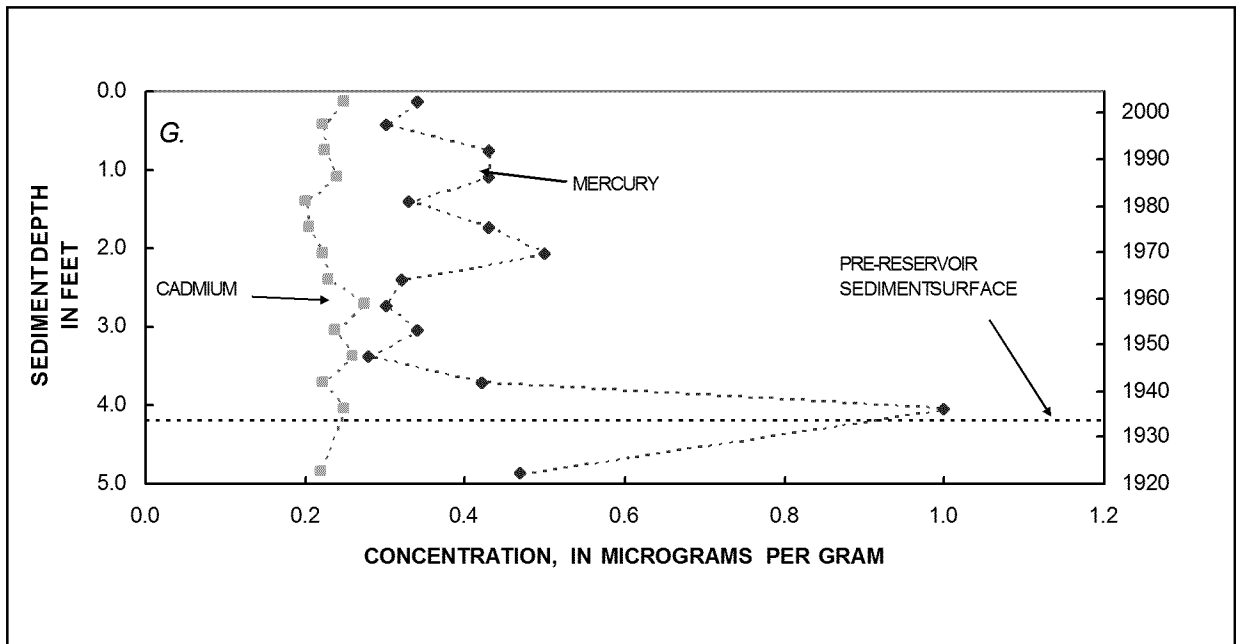


Figure 5. Concentrations or activities of constituents of concern in sediment, as a function of depth and time in Weber Reservoir, in the northern Walker River Basin, Nevada, on June 23, 2005. The year of deposition was estimated assuming a deposition rate of 0.06 foot per year and no sediment compaction--Continued

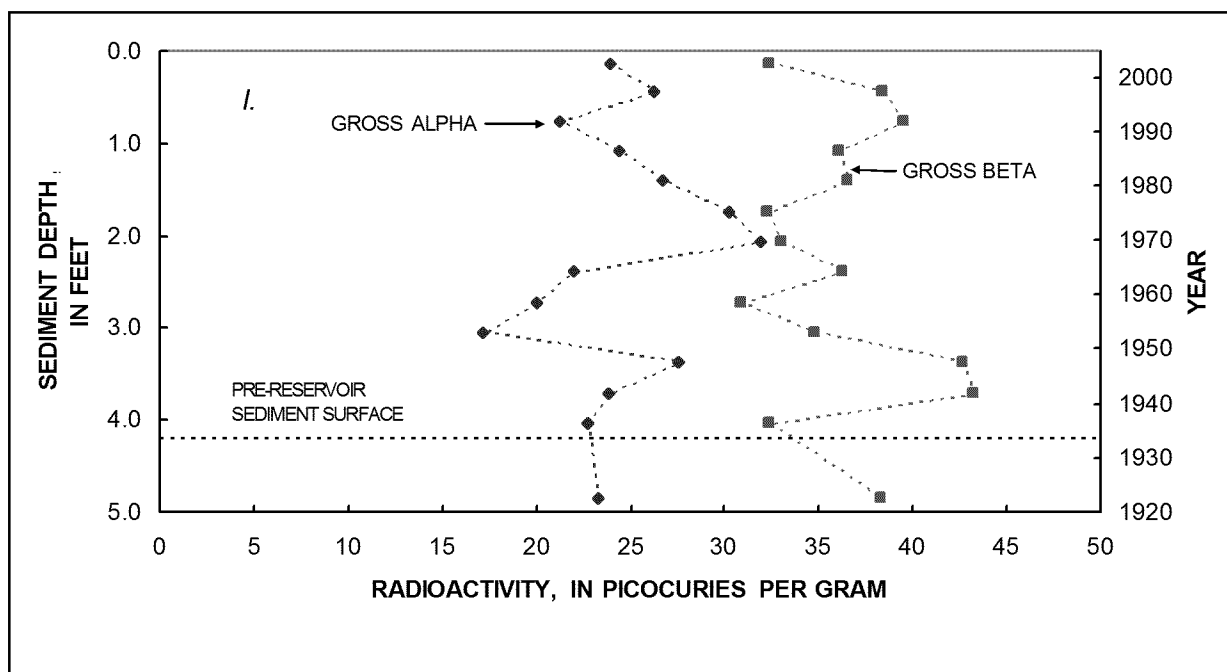


Figure 5. Concentrations or activities of constituents of concern in sediment, as a function of depth and time in Weber Reservoir, in the northern Walker River Basin, Nevada, on June 23, 2005. The year of deposition was estimated assuming a deposition rate of 0.06 foot per year and no sediment compaction--Continued.

Maximum concentrations and activities of constituents of concern in the reservoir-bottom core samples, the location in the sediment profile, and the estimated period of sedimentation for each maximum are listed in table 7. Maximum concentrations of 10 of the constituents of concern listed in table 3 (aluminum, arsenic, beryllium, cadmium, copper, iron, lead, manganese, thorium, and zinc) are from the sub-sample 2.6–2.9 ft below the sediment surface, which represents sedimentation during 1957–62 (Fig. 5). Seventeen of the 37 other analytes listed in table 2 also have maximum concentrations in this depth interval (table 4). Maximum concentrations of chromium and nickel are from the 1.2- to 1.6-ft interval that represents deposition during 1979–84 and secondary peaks were from the sub-samples representing deposition during 1957–62 (2.6–2.9 ft). Maximum concentrations of uranium are from two adjacent samples from the 3.5- to 4.2-ft interval, which represents 1935–46 deposition. Isotopes of radium (^{226}Ra and ^{228}Ra) and gross alpha radioactivity have maximum activities from the 1.9- to 2.2-ft interval representing deposition during 1968–73. The maximum gross beta radioactivity was detected in two adjacent samples from the 3.2- to 3.9-ft interval that represents deposition during 1940–51. Maximum concentrations of mercury and molybdenum were from the sub-sample deposited during 1935–40.

Table 7. Maximum concentration or activity of constituents of concern, depth of subsamples from sediment core, Weber Reservoir, northern Walker River Basin, Nevada, 2005.

[Concentrations and activity values are rounded ft, feet; µg/g, micrograms per gram; pCi/g, picocuries per gram]

Constituent	Maximum Concentration	Depth (ft)	Sedimentation period
Aluminum	110,000 µg/g	2.6-2.9	1957-1962
Arsenic	32 µg/g	2.6-2.9	1957-1962
Beryllium	3.9 µg/g	2.6-2.9	1957-1962
Cadmium	0.27 µg/g	2.6-2.9	1957-1962
Chromium	68 µg/g	1.2-1.6	1979-1984
Copper	84 µg/g	2.6-2.9	1957-1962
Iron	70,000 µg/g	2.6-2.9	1957-1962
Lead	31 µg/g	2.6-2.9	1957-1962
Manganese	1,900 µg/g	2.6-2.9	1957-1962
Mercury	1.00 µg/g	3.9-4.2	1935-1940
Molybdenum	7.7 µg/g	3.9-4.2	1935-1940
Nickel	38 µg/g	1.2-1.6	1979-1984
Thorium	26 µg/g	2.6-2.9	1957-1962
²³⁸ Uranium	12 µg/g	3.5-4.2	1935-1942
Zinc	170 µg/g	2.6-2.9	1957-1962
Radium-226	2.1 pCi/g	1.9-2.2	1968-1973
Radium-228	2.5 pCi/g	1.9-2.2	1968-1973
Gross alpha radioactivity	32 pCi/g	1.9-2.2	1968-1973
²³² Gross beta radioactivity	43 pCi/g	3.2-3.9	1940-1951
¹ Maximum value equal in two adjacent subsamples.			

Contaminants from the Yerington copper mine site can be delivered to Weber Reservoir by direct fallout of windborne dust, fluvial transport of dust blown from the site to drainages, stormwater runoff from the site into the river, and contaminated ground water discharging into Wabuska Drain and possibly into the Walker River. The National Weather Service cooperative station at Yerington does not collect wind-movement data (www.wrcc.dri.edu/summary/climsmnv.html), and records of stormwater releases from the site are not readily available (Arthur Gravenstein, Nevada Division of Environmental Protection, oral. commun., May 2006).

One analysis of meteorological data collected at the Yerington mine site for calendar year 2003 indicates that the wind direction at this site most frequently is from the southwest (almost 20 percent). However, dust characteristics and analysis of atmospheric transport indicate a threshold wind speed of 20 miles per hour is necessary to redistribute dust from the mine site. In 2003, winds in excess of this threshold were predominantly from the southwest about 5 percent of the time, and from the west and south less frequently (Hamilton and Arno, 2004, p. 10–16), indicating that windborne dust from the mine site can be transported toward WRIR and Weber Reservoir. However, the radiological dose assessment concluded that the potential exposure rate is 200,000 times

less than the radiation that average Nevadans are exposed to from natural background radiation (Hamilton and Arno, 2004, p. 20).

Analysis of precipitation records for 1956–62, the period when maximum values of constituents of concern had the highest frequency, indicates that there were 11 days with more than 0.5 in. of precipitation (Western Regional Climate Center, 2006, accessed April 12, 2006). Seven of those days were during May through September, when precipitation averaged 0.77 in.; a maximum precipitation of 1.1 in. fell on September 17, 1957. During the period of precipitation record at the Yerington station (1914–2006), the probability that 0.01 in. of rain would occur during May through September was less than 10 percent, and the probability that 0.5 in. of rain would occur was less than 1 percent.

During water years (October 1 through September 30) 1943–2005, daily-mean streamflow data for USGS stream-gaging station 10301500, Walker River near Wabuska (Fig. 2, site 6) ranged from less than 1 ft³/s (cubic feet per second) on 14 days in October and November 1977 to 2,740 ft³/s on June 7, 1986. Mean values of daily-mean streamflow for each period representing each core subsample ranged from 358 ft³/s (1979–84) to 37 ft³/s (1933–35), and maximum values ranged from 2,740 ft³/s (1984–90) to 410 ft³/s (1935–40). The mean of daily streamflow values for 1957–62, the period when maximum values for 9 of the 19 constituents of concern had maximum concentrations, was 113 ft³/s, with a maximum streamflow value of 1,900 ft³/s. The period with the largest mean of daily-mean streamflow (1979–84) had the highest concentrations of chromium and nickel, and the period with the largest maximum daily-mean streamflow (1984–90) had the second highest concentrations of copper, iron, and second largest activities of ²²⁶Ra and ²²⁸Ra. The second highest concentration of zinc was measured in this sub-sample, but this concentration also was equaled in four other sub-samples (table 4).

Concentrations and activities of constituents of concern detected in sediment-core samples from the Weber Reservoir indicate varying rates of deposition, but because each sample represents sediment that accumulated over 5–6 years, episodic stormwater releases from the mine, as well as discharge from a contaminated ground water site would be diluted by normal sedimentation. Sediment contaminated at levels that exceed advisory guidelines (table 3) may be responsible for the maximum values shown in figure 5. The samples of river-bottom sediment collected for this study generally had lower contaminant concentrations and activities than the samples of the reservoir-sediment samples (table 5), but the differences are small, largely owing to the geology and mining activities throughout the Walker River Basin.

Mining and mineral exploration have been active in the Walker River Basin since the middle of the 19th century, as evidenced by the elevated mercury concentrations reported in water, sediment and biota (Seiler and others, 2004). All the constituents of concern in the basin are associated with the naturally occurring rocks and mineral deposits that stimulated mineral exploration. More than a century of mining and milling activity has increased the potential for their release into the environment.

SUMMARY

The Walker River Paiute Tribe is concerned that mining operations at the Yerington copper mine site, located in the Singatse Range, near Yerington in Lyon County, Nev., have contaminated the Walker River Indian Reservation. Mining in the Walker River Basin began in the mid to late 1800s; large-scale open-pit mining operations at the site began in 1952 and continued intermittently until closure of the mine in 2000 because of bankruptcy. Investigations authorized by the Comprehensive Environmental Response, Compensation, and Liability Act began in the late 1990s in response to reports that elevated concentrations of trace elements and radionuclides have been measured in ground water, tailings leachate, and leachate-contaminated soil samples.

Consolidated rocks in the Walker River Basin range in age from Triassic to Quaternary and primarily consist of quartz monzonite, granodiorite, basalt, rhyolite, and andesite. Basin-fill deposits consist of unconsolidated alluvial sediments underlying the valley floors and alluvial fan deposits near the base of mountain ranges. Lacustrine clay deposits at least 200-ft thick are exposed near Weber Reservoir.

The East Fork and the West Fork of the Walker River flow into Mason Valley where they converge into the main stem of the river which flows northward into Campbell Valley and ultimately into Walker Lake. The principal use of water in the Walker River Basin is for irrigation of crops and pastures. Extensive networks of canals, ditches, and drains have been constructed to convey water from the river for irrigation. The Wabuska Drain originates at the base of mine tailings and intermittently discharges to the Walker River. Weber Reservoir, the only reservoir on the main stem of the Walker River, was constructed in 1934. Local runoff is ephemeral and occasionally has resulted in flash floods. More than 1 million acre-feet of ground water is in the uppermost 50 feet of saturated alluvial aquifers beneath Mason Valley.

The U.S. Geological Survey, in cooperation with the Walker River Paiute Tribe, began an investigation in 2005 to establish a chronology of the sediment quality of Weber Reservoir. Bottom-sediment samples were collected from seven locations that are tributary to Weber Reservoir and from two sediment cores from the reservoir. Samples were analyzed for selected major and trace elements, and radionuclides. Three sites were selected to characterize the chemical quality of bottom sediment in the river upstream of the Yerington mine site, and four sites, including one on Wabuska Drain, were selected to characterize sediment downstream from the mine site. Two sediment cores were collected from Weber Reservoir: a 2.1-foot core was collected when the reservoir had an ice layer that limited access to the preferred sampling location and a 4.0-foot core was collected later near Weber Dam. Two additional samples were collected from 4.2 to 4.6 feet beneath the sediment surface using a peat borer-type sampler.

Sediment samples were analyzed for cesium-137, which is an anthropogenic isotope that has been used as an age marker for periods of above-ground nuclear weapons testing. Also analyzed were constituents identified as being potentially toxic or carcinogenic or that have been measured in samples from the Yerington copper mine site at levels that are greater than background. Bottom-sediment samples represent sediment that was moving within the river system in 2005. Sediment-core data from Weber Reservoir represent a chronologic history of the sediment quality in the Walker River above Weber Reservoir. Mean concentrations and activities of constituents measured in bottom-sediment samples generally were lower than those measured in reservoir sediment. Advisory concentrations

for iron (21,200 µg/g) and manganese (460 µg/g) were exceeded in all samples, and the advisory concentration for arsenic (33 µg/g) was equaled in one riverbed sample. The concentration of mercury in one reservoir sample (1.00 µg/g) is near the advisory concentration (1.06 µg/g). Concentrations of mercury in all samples, except one bottom-sediment sample from the West Walker River, exceeded the sediment effects threshold concentration that may adversely affect freshwater invertebrates in Ontario, Canada (0.2 µg/g). No other sediment advisory concentration or activity was exceeded. Maximum concentrations of mercury and molybdenum were from the subsample deposited during 1936–40.

Cesium-137 data from the second core collected from Weber Reservoir showed a clearly defined peak that represents the year of maximum above-ground nuclear weapons testing and resulting cesium-137 releases in 1963 in the subsample from a depth 2.2 to 2.5 ft below the sediment surface. The initial detection was in the subsample from a depth 2.8 to 3.2 ft below the sediment surface and represents 1950, when above-ground nuclear weapons testing began. Assuming a linear rate of sedimentation and neglecting density compaction, sediment accumulated in Weber Reservoir at a rate of 0.04 ft/yr during 1950–63, and at a rate of 0.06 ft/yr during 1963–2003 and for the 70-year period 1935–2005. Age estimates are plus or minus 3 years because each subsample was 0.2 to 0.3 ft in length.

Maximum concentrations of aluminum, arsenic, beryllium, cadmium, copper, iron, lead, manganese, thorium, and zinc were in the subsample from 2.6 to 2.9 ft below the sediment surface, which represents sedimentation during 1957–62. Seventeen of the 37 other analytes determined also had maximum concentrations in this subsample. Maximum concentrations of chromium and nickel were in the subsample from the 1.2- to 1.6-ft interval that was deposited during 1979–84, and maximum concentrations of uranium were from two adjacent samples from the 3.5- to 4.2-ft interval that was deposited before the reservoir was constructed until 1944. Both isotopes of radium-226 and radium-228 and gross alpha radioactivity had maximum activities in the samples from the 1.9- to 2.2-ft interval, which was deposited during 1968–73; the maximum gross beta radioactivity was in two adjacent samples from the 3.2- to 3.9-ft interval that was deposited during 1940–51. Maximum concentrations of mercury and molybdenum were from samples from the 3.9- to 4.4-ft interval which represents pre-reservoir sediment.

Contaminants from the Yerington copper mine site can be delivered to Weber Reservoir by direct fallout of windborne dust, fluvial transport of dust blown from the site to drainages, stormwater runoff from the site into Wabuska Drain and the river, and contaminated ground water discharging into Wabuska Drain and possibly into the Walker River. Concentrations and activities of constituents of concern in the sediment-core samples from Weber Reservoir indicate varying rates of deposition; but, because each sample represents sediment that accumulated over a 5- to 6-year period, episodic stormwater releases from the mine site, as well as discharge of contaminated ground water, would be diluted by normal sedimentation. Mining and mineral exploration has been active in the Walker River Basin since the mid-1800s, and all the constituents of concern are associated with naturally occurring rocks and mineral deposits. Samples of river-bottom sediment generally had smaller concentrations and activities than the subsamples from the reservoir core, but the differences were small, probably owing to the geology and mining activities throughout the Walker River Basin.

REFERENCES

- Arbogast, B.F., ed., 1996, Analytical methods manual for the Mineral Resource Surveys Program: U.S. Geological Survey Open-File Report 96-525, 248 p.
- Brown and Caldwell, 2003, Wabuska Drain work plan—Draft final: Carson City, Nev., Brown and Caldwell, prepared for Atlantic Richfield Company, variously paged.
- Hamilton, I.S., and Arno, M.G., 2004, Yerington mine site fugitive dust radiological dose assessment: Bryan, Texas, Foxfire Scientific, Inc., 23 p. and 1 appendix.
- Huxel, C.J., Jr., 1969, Water resources and development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948–65: Nevada Division of Water Resources Bulletin No. 38, 77 p.
- Ingersoll, C.G., MacDonald, D.D., Wang, Ning, Crane, J.L., Field, L.J., Haverland, P.S., Kemble, N.E., Lindskoog, R.A., Severn, Corrine, and Smorong, D.E., 2000, Prediction of sediment toxicity using consensus-based freshwater sediment quality guidelines: U.S. Environmental Protection Agency, Great Lakes National Program Office Chicago, EPA 905/R-00/007, variously paged; accessed March 2006 at <http://www.cerc.usgs.gov/pubs/center/pdfDocs/91126.pdf>
- Knopf, Adolph, 1918, Geology and ore deposits of the Yerington District, Nevada: U.S. Geological Survey Professional Paper 114, 68 p.
- Lemly A.D., and Smith, G.J., 1987, Aquatic cycling of selenium—Implications for fish and wildlife: Washington, D.C., U.S. Fish and Wildlife Service, Fish and Wildlife Leaflet 12, 10 p.
- Ludington, Steve, Moring, B.C., Miller, R.J., Flynn, Kathryn, Hopkins, M.J., Stone, Paul, Bedford, D.R., and Haxel, G.A., 2005, Preliminary integrated geologic map databases for the United States—Western states: California, Nevada, Arizona, and Washington, version 1.0: U.S. Geological Survey Open File Report 2005-1305, unpaginated. [Available on the World Wide Web at <http://pubs.usgs.gov/of/2005/1305/>]
- Moore, J.G., and Archbold, N.L., 1969, Geology and mineral deposits of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bureau of Mines Bulletin 75, 42 p.
- Nevada Division of Environmental Protection, 2002, Administrative Order on Consent: accessed March 6, 2006, at <http://ndep.nv.gov/yerington/AR%20Final%20AOC%2010-24-2002.pdf>
- Nevada Division of Environmental Protection, 2003, Yerington Mine update—December 2003: accessed March 6, 2006 at http://ndep.nv.gov/yerington/yerington_site_site_briefing03.pdf
- Nevada State Library and Archives, 2000, [U.S. Census Bureau] Nevada Census 2000: accessed April 18, 2006, at http://dmla.clan.lib.nv.us/docs/nsla/sdc/census_2000.htm
- Persaud, D.R., Jaagumagi, R., and Hayton, A., 1993, Guidelines for the protection and management of aquatic sediments in Ontario: Toronto, Canada, Ontario Ministry of the Environment and Energy, Water Resources Branch, 23 p.
- Price, J.G., 1995, The Nevada mineral industry—1994: Nevada Bureau of Mines and Geology, Special Publication MI-1994, 57 p.
- Reheis, Marith, 1999, Extent of Pleistocene lakes in the western Great Basin: U.S. Geological Survey Miscellaneous Field Studies Map MF-2323.

- Seiler, R.L., Lico, M.S., Wiemeyer, S.N., and Evers, D.C., 2004, Mercury in the Walker River Basin, Nevada and California—Sources distribution, and potential effects on the ecosystem: U.S. Geological Survey Scientific Information Report 2004-5147, 24 p.
- Seitz, H.R., Van Denburgh, A.S., and La Camera, R.J., 1982, Ground-water quality downgradient from copper-ore milling wastes at Weed Heights, Lyon County, Nevada: U.S. Geological Survey Open-File Report 80-1217, 48 p.
- Shelton, L.R., and Capel, P.D., 1994, Guidelines for collecting and processing samples of stream bed sediment for analysis of trace elements and organic contaminants for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-458, 20 p.
- Stockton, E.L., Jones, C.Z., Rowland, R.C., and Medina, R.L., 2004, Water Resources Data—Nevada, Water Year 2003: Water-Data Report NV-03-01, 679 p.
- Taggart, Jr., J.E., ed., 2002. Analytical methods for chemical analysis of geologic and other materials, U.S. Geological Survey: U.S. Geological Survey Open-File Report 02-223, 26 chapters, accessed January 2005, at <http://pubs.usgs.gov/of/2002/ofr-02-0223/OFR-02-0223.pdf>
- Thomas, J.M., 1995, Water budget and salinity of Walker Lake, western Nevada: U.S. Geological Survey Fact Sheet FS-115-95, 4 p.
- Tingley, J.V., 1992, Mining districts of Nevada: Nevada Bureau of Mines and Geology Report 47, 124 p.
- University of Reno, 1997, Copper mining in Nevada: accessed March 17, 2006, at <http://www.unr.edu/sb204/geology/minetext.html>
- Van Metre, P.C., Wilson, J.T., Fuller, C.C., Callender, Edward, and Mahler, B.J., 2004, Collection, analysis, and age-dating of sediment cores from 56 U.S. lakes and reservoirs sampled by the U.S. Geological Survey, 1992–2001: U.S. Geological Survey Scientific Investigations Report 2004-5184, 180 p.
- Western Regional Climate Center, 2006, Yerington, Nevada—NCDC 1971–2000 Monthly normals: accessed April 12, 2006, at <http://www.wrcc.dri.edu/cgi-bin/cliNORMNCDC2000.pl?nvyeri>

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